Mid-Term Exam. (Int. to Nuc. Eng.)

April 21(MON), 2025. 09:00-10:00

* 객관식 (각 3점)

1. 다음의 핵붕괴 가운데, (A, Z) → (A, Z-1) 에 해당하는 것은?
   ① α 붕괴
   ② 전자 포획
   ③ γ 방출
   ④ β^+ 붕괴

2. $_{88}Ra^{226}$이 자연붕괴하여 $_{82}Pb^{206}$으로 되었다. 그동안 α붕괴와 β붕괴를 각각 몇 번씩 하였는가?
   ① α붕괴 5번, β붕괴 2번
   ② α붕괴 5번, β붕괴 4번
   ③ α붕괴 4번, β붕괴 8번
   ④ α붕괴 4번, β붕괴 4번

Z: 88→82

A: 226→206

α: −4 −2Z

β: +1 Zβ

3. $^{14}_{7}N(\alpha,\ p)^{17}_{8}O$ 반응의 Q-값과 가까운 것을 고르시오. 각 원소의 원자량은 각각 다음과 같다: $^{14}_{7}N$ 14.0030740, $^{17}_{8}O$ 16.9991315, $^{4}_{2}He$ 4.0026032, $^{1}_{1}H$ 1.0078250, $^{1}_{0}n$ 1.008665. 1 amu는 931 MeV.
   ① -1.19 MeV
   ② 1.19 MeV
   ③ -2.79 GeV
   ④ 2.79 GeV

14.0030740 + 4.0026032

→ 1.0078250 + 16.99

4. 1mg의 P^{32}은 몇 큐리(Ci)의 방사능을 내는가? 단, P^{32}의 반감기는 14.3일이다.
   ① 285
   ② 572
   ③ 143
   ④ 352

32g/mol

$1\times10^{-3}\,g \times \frac{1}{32g/mol} \times \frac{\ln 2}{14.3d \times \frac{24h}{1d} \times \frac{3600s}{1h}} \times \frac{1Ci}{3.7\times10^{10}Bq}$

5. 어떤 핵의 개수가 3.7x10^{14}개이고, 이 핵에서 방출되는 방사능이 10 퀴리(Ci)이면 붕괴상수는 무엇인가?
   ① 1 sec^{-1}
   ② 0.1 sec^{-1}
   ③ 0.01 sec^{-1}
   ④ 0.001 sec^{-1}

10Ci: 3.7×10^{11} Bq

$A = \lambda N$

$\lambda = 10^{-3}/s$

6. 다음의 방사선의 분류 중에서 입자방사선에 해당되지 않는 것은?
   ① 헬륨 원자핵
   ② 중성자선
   ③ 감마선
   ④ 베타선

7. 1 MeV 감마선에 대한 납의 선감쇠계수가 0.46 cm^{-1} 이다. 이 감마선을 1천분의 1로 감쇠하기 위해서는 납의 두께를 몇 cm로 해야 하는가? (ln(10)=2.3)
   ① 0.015
   ② 0.15
   ③ 1.5
   ④ 15

$I = I_0 e^{-\mu x}$

$\frac{I}{I_0} = e^{\mu \cdot x}$

$1000 = e^{0.46 \cdot x}$

8. 1 MeV의 에너지를 갖는 고속중성자가 감속재 영역으로 진입하여 0.025 eV의 열중성자로 감속되기까지 가장 적은 충돌이 필요한 감속재는?
   ① D_2O
   ② He
   ③ Be
   ④ Graphite

$200W = 200 J/s \times \frac{1 \text{ fission}}{200 MeV \times \frac{1.6\times10^{-13}}{1MeV}}$

9. 200 W의 열출력으로 운전되는 원자로에서 초당 발생하는 핵분열 횟수는? (핵분열당 200 MeV의 에너지가 방출된다고 가정할 것)
   ① 6.25×10^{12}
   ② 5.40×10^{17}
   ③ 6.25×10^{18}
   ④ 5.40×10^{23}

$1MeV = 1.6\times10^{-13} J$

10. 다음 중 가압경수로의 붕괴열(Decay heat)에 대한 설명 중 옳지 않은 것은?
   ① 붕괴열은 공기의 자연대류로 냉각된다. ?
   ② 원자로를 정지한 직후 붕괴열은 약 7%에 해당한다. O/C
   ③ 붕괴열은 핵분열생성물의 방사성붕괴에 의해 발생하는 것이다. O
   ④ 붕괴열은 정지후 시간이 경과하면 감소한다. O

* Write (3 each)

11. Conversion ratio
12. Bragg peak
13. Delayed neutron
14. Thermal neutron energy [eV]
15. Charge of a single electron [C]

* Explain briefly

16. Draw the schematic of PWR nuclear power plant and explain (6)
17. Derive (a) the most probable energy (4) and (b) the average energy of the particles in Maxwellian distribution. (6)

$$N(E) = \frac{2\pi N}{(\pi k T)^{3/2}} E^{1/2} e^{-E/kT}$$

18. Non 1/v factor (5)
19. 3 major types of gamma ray interactions with matters. (7)
20. Plot the energy dependent elastic and inelastic cross-sections of C and U-238 (5)
21. Describe nuclear fuel cycle (7)
22. Infinite medium에서 초당 S개의 중성자를 방출하는 Point source 가 있을 경우 Flux를 구하라 (8점)

$\frac{d^2u}{dr^2}$ $\frac{4du}{dr}$ + $\frac{2u}{r}$ − $\frac{1}{L^2}ur = 0$

23. Fill the table. (8)

	PWR	PHWR	BWR	HTGR	FBR
Fuel					
Moderator					
Coolant					
Characteristics					

핵공학개론1 - 2025 midterm solution

답은 예전 족보에서 충분히 찾을 수 있을 겁니다. 공부 열심히 하시고, 당해 시험지 첨부하셔서 업데이트 부탁드립니다.
2025. 5. 1 김정빈 올림

Mid-Term Exam. (Int. to Nuc. Eng.)
April 17(WED), 2024. 09:00-10:00

* Write (3 each)

1. Conversion ratio
2. High Level Waste(고준위폐기물) (방사성물질 농도와 열발생량)
3. Delayed neutron
4. Fissile, fertile, and fissionable materials
5. Decay heat

* Explain briefly (5 each)

6. Draw the schematic of PWR nuclear power plant and explain
7. 4.5 w/o Fresh fuel과 Spent fuel의 물질구성
8. Breakdown the energy release per fission
9. Double humped curve according to the neutron energy
10. Energy category of neutron
11. 6 different types of neutron interactions with matters.
12. Non 1/v factor
13. Delayed neutron
14. 3 major types of gamma ray interactions with matters.
15. Describe nuclear fuel cycle
16. Explain the fission and fusion with the figure.

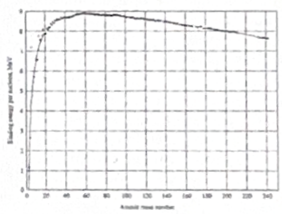


Figure 2.8 Binding energy per nucleon as a function of atomic mass number.

17. Plot the energy dependent elastic and inelastic cross-sections of C and U-238

18. Fill the table. (10)

	PWR	PHWR	BWR	HTGR	FBR
Fuel					
Moderator					
Coolant					
Characteristics					

* Calculate

19. Rest mass of the electron in MeV (m_e = 9.1095 * 10^{-28} g) (5)
20. Derive diffusion equation using Fick's law. (10)
21. Neutron flux from the point source emitting S neutrons per second.
22. Group diffusion equation을 쓰고 각 항을 설명하라 (11)

핵공학개론1 - 2024 Midterm Solution

1. Conversion ratio

Also called Breeding ratio: Average number of fissile atoms produced in a reactor per fissile fuel atom consumed (L9 pg.5). Reactors that convert nor breed but simply consume fuel are called burners.

2. High Level Waste (고준위폐기물) (방사성물질 농도와 열발생량)

For High Level Waste(HWL) the criteria is:

(1) Concentration: RN that emits alpha particle (half life: $>$ 20 year), 4000 Bq/g

(2) Heat generation: $>$ 2 kW/m^3

3. Delayed Neutron

Neutrons that are emitted after a brief period of time, or after a fission event.

4. Fissile, fertile and fissionable materials

Fissile: materials that can be fissioned with thermal neutron
Fertile: materials that can be converted to a fissile material after absorbing a neutron
Fissionable: Fissile + Fertile

5. Decay heat

Heat that is released from the nuclear fuel after the reactor is shut downed.

6. Draw the schematic of PWR nuclear powerplant and explain

7. 4.5 w/o Fresh fuel 과 Spent fuel의 물질구성

Fresh fuel with 4.5 w/o: 4.5% U-235, 95.5%(rest) U-238
Spent fuel: 1.0% U-235, 95.5% U-238. The rest is fission product and fission product($\tilde{4}$6%), Pu, and Minor actinide(Np, Am, Cm)

8. Breakdown the energy release per fission

Around 200 MeV of energy is deposited after a single nuclear fission. 168 MeV of energy is released as fission fragment's kinetic energy, alongside with prompt γ rays(7 MeV) and fission neutron's kinetic energy(5 MeV). The Fission product's decay releases additional β: 8 MeV, γ: 7 MeV, neutrino(ν): 12 MeV. Note neutrino energy is not recoverable.

9. Double humped curve according to the neutron energy

peak at around 95 and 135.

10. Energy category of neutron

Cold: $<$ meV
Slow: $\leq$ 0.5 eV - contains thermal neutron
Intermediate(epithermal): 0.5 eV - 10 keV
Fast: 10 keV - 10 MeV
High Energy: $>$ 10 MeV

11. 6 Different types of neutron interaction with matters

(n, el): elastic scattering
(n, inl): inelastic scattering
(n, γ): radiative capture
(n, f): fission reaction
(n,2n), (n,3n): neutron production reaction
(n, p), (n, α): charged particle production reaction

12. Non 1/v factor

At the neutron energy level of low to intermediate range, most of the element's radiative capture cross section(σ_γ) shows 1/v behavior. However, some elements doesn't show these kind of phenomenon. The problem is that these elements are quite important in nuclear fuel and reactor physics - such as U-238 and zirconium. In order to compensate for this, we use non 1/v factor, or g_a.

~~**13. delayed neutron**~~

14. 3 major types of gamma ray interactions with matters

Photoelectric effect: The gamma ray transfers its whole energy to atom's orbiting election, and the electron gets emitted.
Compton scattering: The gamma ray scatters with the atom's orbiting electrion, loses energy during the process and the electron gets recoiled out.
Pair production: A gamma ray having larger energy than 1.022 MeV(rest mass energy of 2 electron) converts to position and electrion.

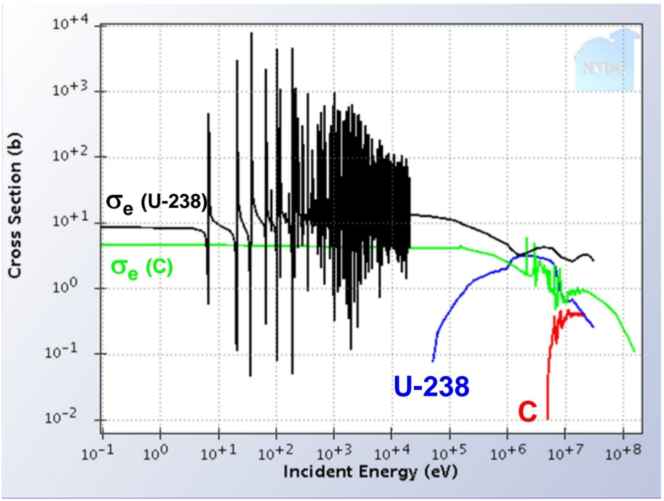
15. Describe nuclear fuel cycle

Front end: 채광(mining) - 정광(milling: to yellowcake) - 변환(Conversion to UF_6) - 농축(Enrichment) - 성형가공(Fuel fabrication to pellet) - 원자로 사용
Back end: 원자로에서 제거 - 냉각(Spent fuel pool 에서 decay heat 식힘) - 재처리(Reprocessing) or 고준위방폐장(High Level Waste Disposal)

16. Explain the fission and fusion with the figure

철 기준으로. The binding energy per nucleus increases as the A(mass number) goes up until around $A = 60$. This means that the more you add a nucleus to a certain atom, the more stable it gets.
On the other hand, the BE per nucleus decreases after $A = 60$. This means that if a atom loses it's nucleus, it will get stable. This explains the nuclear fusion, where the heaviest nuclear fusion element is generally a iron($^{58}_{26}$Fe), and elements with high A (like urainum or plutonium) tends to undergo fission.

17. Plot the energy dependent elastic and inelastic cross-section of C and U-238



The neutron's energy has to be larger than the target nucleus' **Threshold Energy**; this is the reason why the inelastic scattering happens after a certain energy level. For example, the threshold energy for U-238 is 44 keV, and for C-12, 4.8 MeV. The heavier nuclides tend to have smaller threshold energy than the lighter nuclei (this is related to fission)

18. Fill in the table (that one - refer to the 22 midterm)

19. Rest mass of the electron in MeV ($m_e = 9.1095 \times 10^{-28}\ g$)

$$E = m_0c^2$$

The speed of light is $3.0 \times 10^8\ m/s$. Using this and converting Joule to MeV ($1\ MeV = 1.6 \times 10^{-13}\ J$) will result 0.511 MeV.

$$E = 9.1095 \times 10^{-31}\ kg \times (3.0 \times 10^8\ m/s)^2 \times \frac{1\ MeV}{1.6 \times 10^{-13}\ J} = 0.5124\ MeV$$

Speed of light is actually $2.9979 \times 10^8\ m/s$. Using this value will result a value more closer to the known one.

20. Derive diffusion equation using Fick's law

The Equation of continuity: Consider an arbitrary volume within a medium containing neutrons:
The 'rate of change in number of N in V' must equal: 'rate of production of N in V' - 'rate of absorption of neutrons

in V' - 'rate of leakage of neutrons from V'. Writing each terms down:

- Rate of change in number of neutrons: $\int_{\forall} \frac{\partial n}{\partial t}\, d\forall$
- Production rate: $\int_{\forall} s\, d\forall$
- Absorption rate: $\int_V \Sigma_a \phi\, d\forall$

For the leakage rate, you need to use divergence theorem.

$$\text{Leakage rate} = \int_A \mathbf{J} \cdot \vec{n}\, d\vec{A} = \int_{\forall} div\ \mathbf{J}\, d\forall = \int_{\forall} \nabla \cdot \mathbf{J}\, d\forall$$

Gathering this all up, we can write down:

$$\int_{\forall} \frac{\partial n}{\partial t}\, d\forall = \int_{\forall} s\, d\forall - \int_{\forall} \Sigma_a \phi\, d\forall - \int_{\forall} div\ \mathbf{J}\, d\forall$$

Differentiating both sides with the $\forall$ results ($\frac{d}{d\forall}$):

$$\frac{\partial n}{\partial t} = s - \Sigma_a \phi - div\ \mathbf{J}$$

The neutron current density, by **Fick's Law**, is defined as:

$$\mathbf{J} = -D\ grad\phi = -D\nabla\phi$$

Assuming the steady state and we will get the diffusion equation

$$D\nabla^2\phi - \Sigma_a\phi + s = 0$$

We normally divide both above equaions with the diffusion coefficient:

$$\nabla^2\phi - \frac{\Sigma_a}{D}\phi + \frac{s}{D} = 0 \xrightarrow{L^2 = \frac{D}{\Sigma_a}} \underline{\boldsymbol{\nabla^2\phi - \frac{1}{L^2}\phi + \frac{s}{D} = 0}}$$

21. Neutron flux from the point source emitting S neutron per second

From Q20:

$$\nabla^2\phi - \frac{1}{L^2}\phi + \frac{s}{D} = 0$$

This is normal diffusion equation. In the question's case, where there is a point source emitting S neutrons. There will be no neutron production inside the volume except the source. This makes $s = 0$. Re-writing the equation:

$$\nabla^2\phi - \frac{1}{L^2}\phi = 0$$

We should consider it in the spherical corrdinate. The laplacian to r direction is:

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d\phi}{dr}\right) - \frac{1}{L^2}\phi = 0 \quad \rightarrow \quad \frac{d^2\phi}{dr^2} + \frac{2}{r}\frac{d\phi}{dr} - \frac{1}{L^2}\phi = 0$$

Substituting to $w = r\phi$, and solving the ODE ultimately results:

$$\phi(r) = \frac{Se^{-r/L}}{4\pi Dr}$$

Note, the below equation:

$$\phi = \frac{S}{4\pi r^2}$$

Does not consider any absorption or other events - it only considers the geometric spreading. The neutron flux derived from diffusion equation consideres geometric spreading and absorption reaction.

22. Group diffusion equation을 쓰고 각 항을 설명하여라

The purpose of even doing the grouping is to descritize the energy - making it easier to compute. However, there

are much things to consider. Lets write down the group diffusion equation:

$$D_g \nabla^2 \phi_g - \Sigma_{a,g}\phi_g - \sum_{h=g+1}^{N} \Sigma_{g\to h}\phi_g + \sum_{h=1}^{g-1} \Sigma_{h\to g}\phi_h = -s_g$$

Explaining each term:

- $D_g \nabla^2 \phi$: Rate of leakage: this term denotes the flux in the g energy group leaking out from our domain of interest. $-div\mathbf{J} = -\nabla \cdot (-Dgrad\phi) = D\nabla \cdot \nabla\phi = D\nabla^2\phi$.
- $-\Sigma_{a,g}\phi_g$: Rate of absorption in the energy group g; when the neutron is absorbed, its removed from the domain of interest, hence the minus sign.
- $-\sum_{h=g+1}^{N} \Sigma_{g\to h}\phi_g$: Rate which the neutron with energy g gets scattered to the lower energy group, $g+1$ to N.
- $\sum_{h=1}^{g-1} \Sigma_{h\to g}\phi_h$: Rate which the neutron with higher energy than g gets scattered into the energy group g.

This above amount, the loss of neutron by leakage, absorption, and scattering should equal the amount of production inside the domain: s_g. To make the equation, the minus sign is added.

김민주

Mid-Term Exam. (Int. to Nuc. Eng.)

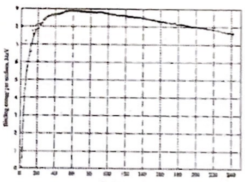
April 21(THU), 2022. 15:00-

* Write (3 each)

1. Charge of a single electron [C]
2. Bragg peak
3. Barn [cm^2]
4. Fissile, fertile, and fissionable materials
5. PWR, BWR, HTGR, FBR (2 each)

* Explain briefly (5 each)

6. Formula for ~~atomic~~ nucleus radius and explain $R = 1.25 \times A^{1/3}$ fm → 원자의 반지름은 질량수의 1/3 승에 비례
7. Explain the definition and meaning of collision parameter α .
8. Breakdown the energy release per fission
9. Double humped curve (according to the neutron energy)
10. Energy category of neutron
11. 6 different types of neutron interactions with matters.
12. Non 1/v factor
13. Delayed neutron
14. 3 major types of gamma ray interactions with matters.
15. Describe nuclear fuel cycle
16. Explain the fission and fusion with the figure.
17. Plot the energy dependent fission cross-section of U-235



18. Fill the table. (10)

boiling water (BWR) · gas-cooled (HTGR) · fast breeder reactor (FBR)

	PWR	PHWR	BWR	HTGR	FBR
Fuel	enriched U	natural U	enriched U	enriched U	Pu-239
Moderator	H_2O	D_2O	H_2O	graphite	X
Coolant	H_2O	D_2O	H_2O	He, CO_2	Liquid metal, Na
Characteristics	150atm	on-power refueling	allow boiling	low P, bulky	breeder burner

* Textbook (10 each)

19. Describe the Passive Safety System of AP600 PWR.
20. Why did the Nautilus win the Seawolf in the nuclear submarine competition?

핵공학개론1 - 2022 Midterm Solution

1. Charge of a single electron [C]: 1.6×10^{-19} C

2. Bragg peak
하전입자가 물질 속을 이동할 때, 그 물질을 이온화시키면서 진행하는데, 이때 이온화시키는 정도가 입자가 멈추기 직전 즈음 가장 크게 된다(비전리도가 가장 크다). 이 것을 그래프로 표현하면, 입자가 비정 거리에 가까워질수록 '피크'를 나타내게 되는데. 이 피크를 Bragg peak 라고 한다.

3. Barn $[cm^2]$
미시단면적(microscopic cross section, σ)의 표현에서 주로 사용되는 단위. $1\ Barn = 10^{-24}\ cm^2$

4. Fissile, fertile, and fissionable material
Fissile: 열중성자나 저속중성자를 흡수함으로서 핵분열할 수 있는 물질.
Fertile: 중성자를 흡수하여 Fissile 로 바뀔 수 있는 핵종, 혹은 속중성자 / 고에너지중성자를 흡수하여 핵분열할 수 있는 물질
Fissionable: Fissile + Fertile

5. PWR, BWR, HTGR, FBR
PWR: Pressurized Water Reactor
BWR: Boiling Water Reactor
HTGR: High Temperature Gas-Cooled Reactor
FBR: Fast Breeder Reactor

6. Formula for nucleus radius and explain
원자의 반지름은 질량수의 1/3승에 비례한다:

$$R = 1.25A^{1/3}\ fm$$

7. Explain the definition and meaing of collision parameter α
입자가 질량수 A인 핵자와 한번 충돌 시 가질 수 있는 최소 에너지에 대한 비례수:

$$E'_{min} = E_{incident} \cdot \alpha$$

$$\alpha = \left(\frac{A-1}{A+1}\right)^2$$

8. Breakdown the energy released per fission
총 200 MeV. 이중 85% (약 168 MeV) 가 핵분열 생성물의 운동에너지로 전달되고, 나머지:
FP 붕괴 베타: 8 MeV, FP 붕괴 감마: 7 MeV, 중성미자: 12 MeV(회수불가), 즉발 감마: 7 MeV, 핵분열중성자: 5 MeV (2-3개 전체) 등이 있다.

9. Double humped curve according to the neutron energy
그 혹 두개 달린 커브임. 한 핵종이 중성자에 의해 핵분열을 할 때, 이때 2개의 핵분열생성물이 나오고, 어떤 한 Incident Neutron의 에너지에 대해 핵분열생성물의 질량수의 확률적 분포를 나타낸 것이 double humped curve 이다. 피크는 보통 97랑 135 즈음에 위치한다. 이때 incident neutron의 에너지가 클수록 double humped curve의 valley(안으로 푹 꺼진 구역)가 위로 올라오는 현상을 보인다.

10. Energy category of neutron
Cold: $<$ meV
Slow: $\leq$ 0.5 eV - contains Thermal neutron (0.0253 eV)
Intermediate(epithermal): 0.5 eV - 10 keV
Fast: 10 keV - 10 MeV
High Energy: $>$ 10 MeV

11. 6 different types of neutron interaction with matters
1. Elastic Scattering (σ_e) 2. Inelastic Scattering (σ_i) 3. Radiative capture (σ_{gamma}) 4. Fission (σ_f) 5. Charged particle production((n,p), (n,α)) 6. Neutron production reaction((n,2n), (n,3n))

12. Non 1/v factor
대부분의 핵종은 low to intermediate 범위 에너지 중성자에 대해서, Radiative capture의 반응단면적은 속도의 반비례하는 양상을 나타낸다. ($1/v$). 하지만 몇몇 핵종들은 이러한 양상을 보이지 않기에 보정해주는 인자를 계산한 것이 non 1/v factor 이다.

13. Delayed Neutron
핵분열 이후 어느정도의 시간이 지난 이후 Fission Fragment에서 방출되는 중성자를 지발중성자라고 한다. few msec - a few

min. 0.65% 의 방출 중성자가 여기 해당된다.

14. 3 major types of gamma ray interaction with matter

1. Photoelectric Effect (광전효과): 물질에 감마선을 조사하였을 때 물질의 궤도전자가 에너지를 받아 방출되는 반응
2. Compton scattering : 감마선이 궤도전자와 상호작용하여, 일부 에너지를 전달하고 감마선은 산란된다. 이때 전자는 남은 에너지를 받아 반도된다.
3. Pair production (전자쌍생성): 감마선이 물질내부에서 쿨롱장의 영향을 받아 소멸하고 양전자와 음전자를 생성한다. 이때 감마선의 에너지는 1.022 MeV 이상이여야 하고, 이 1.022 MeV를 제외한 에너지는 양전자와 음전자가 운동에너지로 불균등하게 나누어 가진다.

15. Describe nuclear fuel cycle

Once-through cycle: Uranium Ore →Yellow cake (U3O8) →UF6 (for enrichment of U235) →UO2: fabricated to fuel pellets →Spent fuel pool: cooled →waste disposal

16. Explain the fission and fusion with the figure - Binding energy per nucleus diagram

한 핵종에 대해 핵자당 결합에너지(Binding energy)를 나타낸 다이어그램에서, Fe (질량수 약 58 - 그래프에서 최대값은 A=60)가 핵자당 가장 큰 결합에너지를 가진다. Fe 보다 질량수가 작은 핵종은 핵융합을 할 수록(A 증가하는 방향) 핵자당 결합에너지가 커지므로, 안정화되기 해 핵융합을 하고, Fe보다 질량수가 큰 핵종은 핵분열을 할 수록 (A 감소하는 방향) 결합에너지가 커지므로 핵분열을 한다.

17. Plot the energy dependent fission cross section of U-235

10 eV 이하의 incident neutron에 대해서는 1/v 양상을 보이며, 10 eV 이상의 intermediate neutron range 에서는 공명현상(resonance)를 보인다. 공명영역 이후에는 반응단면적이 비슷한 수준으로 유지된다.

18. Fill the table:

PWR - Fuel: Enriched U, Moderator: H2O, Coolant: H2O, Characteristic: primary loop is 15MPa, etc.
PHWR - Fuel: Natural U, Moderator: D2O, Coolant: D2O, Characteristic: on-power refueling(calandria), CANDU type, etc.
BWR - Fuel: Enriched U, Moderator: H2O, Coolant: H2O, Characteristic: allows boiling in core - low primary side P, etc.
HTGR - Fuel: Enriched U, Moderator: Graphite, Coolant: He, CO2, Characteristic: Low P, High outlet temp but bulky, etc.
FBR - Fuel: U238, Pu239, Moderator: None, Coolant: Liquid metal(Na, Pb, Bi), Characteristic: breeder - converts fertile to fissile, etc.

* PWR과 BWR의 primary coolant에 사용되는 boric acid는 반응성 조절을 위한 용도. 붕소는 중성자를 흡수하는 독물질인데, boric acid가 많으면 중성자 흡수를 많이해서 반응도가 떨어지고, vice versa.
* FBR은 속중성자/고에너지중성자를 사용하기에 감속재를 필요로 하진 않음.
* HTGR에서 He가 감속재로 사용될 수 있지 않냐고 질문할 수 있는데, 아무리 collision pararmeter(or lethargy) 가 높다해도 밀도가 낮아서 효과적으로 감속시키지는 못함. 그래서 흑연 쓰는거.

19. Describe the Passive Safety System of AP600 PWR

Passive emergency core cooling system: IRWST (In-containment Refueling Water Storage Tank) - requires no pump to inject that boron water into the core in case of LOCA or core accident.
격납건물내 핵연료재장전수탱크(IRWST). 기존 RWST는 격납건물 외부에 코어보다 높은 위치에 재장전수를 놔 두는데, IRWST는 격납건물 내 코어보다 아래에 놔둠. 그러면 passive safety가 안된다고 물을 수 있는데, 만약 LOCA 가 발생한다면 reactor vessel 내부 압력이 급강하하는 반면, 격납건물 압력은 올라가게됨(물 새어나오니까). 이러면 격납건물 압력과 vessel내 압력차로 인해서, IRWST에 있는 물이 코어로 쏴지게 됨. 이렇게 passive safety를 달성함.

Westinghouse의 AP(Advanced Passive) 노형 (AP-600, AP-1000)이 이게 가능한 이유는, Containment 가 콘크리트 말고도 안쪽의 steel로 방호벽이 한겹 더 있음. 이거 때문에 압력변화가 바로 적용될 수 있는 것.

20. Why did Nautilus win the Seawolf in the nuclear submarine competition?

LMFBR(Seawolf: SSN-575) vs PWR(Nautilus: SSN-571) type - seawolf used sodium/potassium cooled fast breeder reactor, and nautilus used conventional PWR. Introduction of sodium metal inside such vessel can be a significant downside, leading to some reliability issues - since molten sodium metal is corrosive and is extremely reactive with water. If there happens to be a hull breach, it would be detrimental to the submarine.

You might say that why there is no Nautilus class submarine in US's arsenal, and all the seawolf nowadays uses PWR - which is counter-intuitive. In fact, the modern Seawolf class: SSN-21, which is launched in 90s, is totally different from the previous Seawolf.

Also take note that the reason why nuclear submarine uses fast/intermediate range(epithermal) neutrons. Of

course there is a reason that the xenon production is accelerated when using low energy neutrons, but the main reason why SSN uses these neutrons is simply related to their core size. See, the reactor size inside SSN is very small, and there's no way to moderate those fast fission neutrons all the way down to the thermal range. Moreover, U235 or Pu239 fissions well even if the neutron is fast. Thats why nuclear submarines are forced to use neutrons having energy more than thermal. 교수님이 말씀해주신거랑 조금은 다름.

2017

Mid-Term Exam. (Int. to Nuc. Eng.)

April 18(Tue), 2017. 12:00-13:15

* Describe briefly the followings: (4 each)

1. Avogadro number
2. Thermal neutron energy [eV]
3. Thermal neutron velocity [m/s]
4. Charge of a single electron [C]
5. Speed of light [m/s]
6. Rest mass of an electron
7. Decay heat
8. Double humped curve
9. Fissile, fertile, and fissionable materials

10. Calculate the mean-life of a radioactive isotope whose decay constant is λ and mean free path of a neutron at a medium of Σ_t . (8)

$\int_0^\infty x,\quad p(x) = \Sigma_t \cdot e^{-\Sigma_t x}$

11. Derive equation for neutron energy after scattering (7)

$$E' = \frac{E}{(A+1)^2}\left(\cos\theta + \sqrt{A^2 - \sin^2\theta}\right)^2$$

12. Derive (a) the most probable energy (4) and (b) the average energy of the particles in Maxwellian distribution. (6)

$$N(E) = \frac{2\pi N}{(\pi k T)^{3/2}} E^{1/2} e^{-E/kT}$$

13. Explain the fission and fusion with the figure. (6)

50미만 60 이상 100 이상 ↓

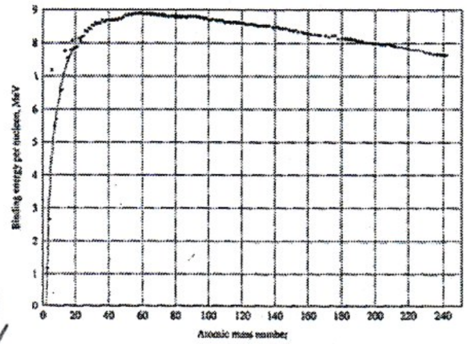


Figure 2.8 Binding energy per nucleon as a function of atomic mass number.

* List up and describe shortly the followings:

14. 6 different types of neutron interactions with matters. (10)
15. the energy categories of neutrons. (7)
16. 3 major types of gamma ray interactions with matters. (10)
17. Plot the energy dependent fission cross-section of U-235 (7)
18. Kinetic energy for a particle for $E > 0.02\ E_{rest}$, $E < 0.02\ E_{rest}$, and $m = 0$. (6)

핵공학개론1 - 2017 midterm

1. Avogadro number: number of molecule(particle) in a 1 mol. $N_A = 6.02 \times 10623$

2. Thermal neutron energy: 0.0253 ev

3. Thermal neutron velocity: 2200 m/s

4. Charge of a single electron: $1.6 \times 10^{-19}\ C$

5. Speed of light: $3.0 \times 10^{8}\ m/s$

6. Rest mass of an electron: 0.511 MeV. *cf). $m_e = 9.1095 \times 10^{-28}\ g = 0.000548\ amu$

7. Decay heat: Heat generated after running the NPP. $P = 0.066P_0$. Note: Burnup rate: $1.05 \cdot P\ g/day$, Fission Rate: $2.7 \times 10^{21}\ P\ fissions/day$

8. Double humped curve: Probability function where it shows the distribution of the mass(A) of the fission fragment in a fission event.

9. Fissile, fertile, and fissionable material: Fissile-can be fissioned with thermal neutron, fertile-can be converted to fissile after a reaction with neutron, fissionable= fissile + fertile

10. Calculate the mean life of a radioactive isotope whose decay constant is λ and mean free path of a neutron at medium of Σ_t.
I guess there is 2 questions: 1. mean life(τ) of such isotope having half life of λ, and 2. Mean free path of a neutron at a medium of Σ_t. For the first question:

$$\tau = \frac{1}{\lambda}$$

The mean free path(λ)

$$\text{survival probability } p(x) = e^{\Sigma x}$$
$$\lambda = \int_{x=0}^{\infty} xe^{-\Sigma x}\Sigma\ dx = -xe^{-\Sigma x}\Big|_0^{\infty} + \int_0^{\infty} e^{-\Sigma x}\ dx = \frac{1}{\Sigma}\ [cm]$$

11. Derive equation for neutron energy after scattering:

$$E' = \frac{E}{(A+1)^2}\left(\cos\theta + \sqrt{A^2 - \sin^2\theta}\right)^2$$

12. Derive the most probable energy, and average energy of the particles in Maxwellian distribution

$$N(E) = \frac{2\pi N}{(\pi kT)^{3/2}} E^{1/2} e^{-E/kt}$$

13. Explain the fission and fusion with the figure (Binding energy per nucleon as a function of atomic mass No.)
refer to the other year's 족보

14. 6 different types of neutron interactions with matters.
elastic, inelastic, radiative capture, fission, charged particle production, neutron production

15. The energy categories of neutrons
cold : less than mev
slow: less than 0.5 eV
intermediate 0.5 ev to 10 keV
fast: 10 keV to 10 MeV
high energy: more than 10 MeV

16. 3 major types of gamma ray interactions with matter
Photoelectric effect, Compton scattering, Pair production

17. Plot the energy dependent cross-section of U-235

I mean.. there is so much stuff to plot here. If we are only considering the capture XS and fission XS, the graph will have a downward right form (1/v) with it's resonance starts to appear around 1 eV.

18. Kinetic energy for a particle for $E > 0.02E_{rest},\ E < 0.02E_{rest},\ m = 0$

When the en for zero mass, $E = pc$